A new horizon in electrostatic charge induction on hoverflies

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Abstract

Pollinator bees can induce an electrostatic charge on their bodies, and they can also detect the electric field surrounding flowering plants. Here we present the previously unappreciated capacity of hoverfly *Cheilosia albipila* to induce a charge, and we identify the part of the body used for the induction. We found that the thoracic hairs play an essential role in the charge polarity of the hoverfly. We also found that the propleuron hairs are involved in the electrostatic charge induction, and if the hairs from the propleuron area were removed, the flies were unable to induce a charge; on the other hand, even when the prescutum hairs were removed, the flies were still able to induce a negative charge.

Keywords: electrostatic charge induction, faraday pail, *C. albipila,* propleuron hairs

1. Introduction

Electroreception is the ability of a living organism to detect weak electric forces in the external environment that has been long known in aquatic living organisms for example fishes (Kalmijn, 1971) [7], amphibians and platypus (Fritzsch & Wake, 1984; Gregory *et al*., 1987) [4, 6]. Recent studies have provided behavioural and physiological evidence about electroreception in insects (Clarke *et al*., 2013; Sutton *et al*., 2016; Khan *et al*., 2021) [3, 14, 9]. Bumblebees, *Bombus terrestris* (Clarke *et al*., 2013) [3], honey bees, *Apis mellifera* (Greggers *et al*., 2013) [5] and hoverfly, *Chlosia albipila* (Khan *et al*. 2021) [9] have shown the ability to detect weak electric fields using different mechanosensory organs. Bumblebees and hoverflies use mechanosensory hairs as a sensory basis for electric field detection and electroreception (Sutton *et al*., 2016; Khan *et al*., 2021) [14, 9]. Honeybees seem to utilize their antennae to detect weak electric fields (e-fields) (Greggers *et al*., 2013) [5]. Bumblebees and hoverflies can discriminate between rewarding and non-rewarding flowers based on electric information (Clarke *et al*., 2013; Khan *et al*., 2021) [3, 9]. Hoverflies use their thoracic hairs to detect the electric field surrounding flowers (Khan *et al*., 2021) [9]. But there is no study available about the part of the thorax involved in the electrostatic charge induction on the hoverflies to my best knowledge.

The present study was conducted to investigate the following questions: i) which part of the thoracic region is used by hoverflies to induce a charge on their bodies? ii) What happens if these hairs are removed?

2. Materials and methods

2.1 The study organisms

Cheilosia albipila is widely distributed throughout Pakistan (Khan & Hanif, 2016) [8]. Specimens were collected from Chakwal (32°55′49″N, 7251′20″E) by hand net and then transferred into rearing boxes. Like most of the *Cheilosia*, it is black in color and has hairs on their bodies. The adult flies have about 1.5g (average weight of 10 flies) body weight and 9-11mm wingspan.

2.2. The experimental set-up

2.2.1. Experiment 1: The nature of the charge on flies

The nature of the charge (positive or negative) carried by hoverflies was determined using a JCI 147 Faraday pail and a JCI-140 non-contact voltmeter calibrated as a Coulomb meter (Unilab) as described in the literature (McGonigle & Jackson, 2002; Clarke *et al*., 2013) [10, 3]. The pail is divided into two plates; the upper plate is a calibrated capacitor with capacitance *C*, while the lower plate has a voltage *V*, which is relatively proportional to the net charge by $q = CV$ and is then read by the voltmeter (Clarke *et al.*, 2013) [3]. Therefore, the change in the voltage on the lower plate caused by the fly when it lands on the lower plate is the net equal to the charge in pico Coulomb (pC). Charge measurement is possible because the net inverse charge on the hoverfly is induced on the pail surface (by Faraday electrostatic induction). To determine the nature of a charge on *C. albipila*, specimens were trained to fly freely into a Faraday pail and sit on the lower plate. About 20 individuals were released one by one into the pail to determine the charge, and the results were displayed on the calibrated voltmeter, which indicates the net charge of the object in pC.

2.2.2 Experiment 2: Effect of thoracic hair removal on the electrostatic charge induction on flies

In the second part of the experiment, the thoracic hairs of the flies were removed under an Olympus stereomicroscope (SZX16). The flies were etherized and plugged into queen holders (used for the artificial insemination of queen honey bees) that were slightly modified according to the flies' size. The thoracic part of each fly was kept outside the holder, and the holder was placed under a microscope. To detect the thoracic region involved in the induction of electrostatic charge, the experimental flies were subjected to one of eight treatments: prescutum hair removed, scutum hair removed, scutellum hair removed, propleuron hair removed, prosternum hair removed, mesosternum hair removed, metasternum hair removed, and control. The hairs were removed one by one with a sharp tweezer from the dorsal and ventral portion of the thorax, causing minimal damage to the flies. After hair removal, the flies were placed back into their respective boxes for 24 hours for acclimatization and pain relief before introducing into the Faraday pail. Science takes time, so hairs from only five flies were removed for each treatment, and from these, only three flies for each treatment and each replication were selected. After removing the hairs, the same Faraday pail experiment was repeated with flies from the eight treatments as mentioned above.

2.2.3 Application of treatments
The experimental procedure was applied to three flies in each treatment (i.e., a total of 24 flies). The flies from all the treatments were released one by one into the Faraday pail's flight arena (200 cm length × 110 cm width × 120 cm height). After measuring the charge on each fly, the fly was removed from the pail and returned to its respective box before a new fly was released. We also applied a control as an additional treatment in which no hairs were removed. While the flies were flying inside the Faraday pail, the net inverse charge on their bodies was induced on the pail surface (by Faraday electrostatic induction).

2.2.4. Experiment 3: The measurement of stems' electric potential during fly landing
To determine the role of propleuron hairs in electrostatic charge induction when a fly lands on the plant, flies with removed hairs were allowed into the plant's flight zone for landing. To measure the electric potential of a stem due to the landing of flies on swe*et al*yssum (*L. maritima*), a tungsten electrode was inserted in the stem at the base of the corolla, while the other electrode was grounded by employing the method developed by Stanković and Davies (1996) [12]. The WPI DAM-50 bio-differential amplifier was used to study the electric potential of the stem during the landing of a fly. The electrodes were connected to the amplifier about 3cm from the flower, and the change in the electric potential during the fly's landing on the flower was recorded on the PC using a data acquisition (DAQ) system. The stem's electric potential was measured by calculating the difference between the measurement electrode and the grounded one (Clarke *et al*., 2013) [3]. To let the flies land freely on the flower, a 200×200×200 cm Faraday pail was attached to the releasing chamber of the flies. To avoid the unwanted movement and torque of the electrode due to the air currents caused by the fly, a thin layer of floral foam was used. To test whether the system is working or not, 20 ten-second recordings were made before releasing the flies from the chamber.
This is an essential and significant step to establish the detection and use of electrostatic charges in the behavior of the hoverflies that were investigated. In this step, specimens were released, the first propleuron removed hairs and then control, into a Faraday pail containing flowers of swe*et al*yssum with the same natural fragrance. The same process was repeated three times with (N=10) different individuals of each treatment to minimize the chances of error in results.

3. Statistical analysis
We fitted generalized linear mixed model (GLMER) to analyse the effect of different treatments on the charge induction with a binomial data distribution (Charge =, No charge = 0). To compare the effect of different hair removal treatments on the nature of charge (positive or negative), we used linear mixed effect model (LMER). Multiple comparisons were conducted using Tukey's test with P value ≤ 0.05. Differences in group means of charge after treatment were analysed using Kruskall-wallis one way ANOVA and pairwise multiple comparison procedure (Tukey test) with P-value of ≤ 0.05. A statistical analysis was conducted on R version 3.3.0 (RC Team, 2016).

4. Results
The first experiment related to the nature of charge revealed that 21 (84%) specimens carried a positive charge and 4 (16%) induced no charge, while no one individual was recorded with a negative charge ($q_{mean} = 37.6 \pm 24.6$, SEM = 5.02pC). When the specimens' hairs from the thorax region (prescutum) were removed, the results were surprising; about 20 (80%) of individuals of *C. albipila* were negatively charged while 5 (20%) were recorded with no charge. On the other hand, when the propleuron hairs were removed 100% flies induced no charge on their bodies. Therefore, the mechanosensory hairs of the thorax appear to be the sites for electrostatic induction.
Further experiments were conducted to explore the thoracic part used for electrostatic charge induction by the hoverflies. The series of experiments revealed highly significant effects of different treatments on electrostatic charge induction (Table 1). The intact flies (control) induced a significantly higher charge than all other treatments (prescutum, scutum, scutellum, propleuron, prosternum, mesosternum, metasternum) (Fig. 1). On the other hand, when the prescutum hairs were removed, a negative charge was induced on the bodies of hoverflies (Fig. 2). This experiment revealed that the hoverflies adapted this specific behavior of electrostatic charge induction merely because of the propleuron hairs present on the ventral thoracic region of the body and may be helpful in losing the electron during flight. The intact flies and the flies with propleuron hairs removed had shown the opposite charge (Fig. 3). This finding may have occurred because removing propleuron hairs may increase the ionization energy (the amount of energy taken by the atom to lose its electron), so ultimately, the electron loss is challenging, which yields a fly with no net charge on them.
The total charge transfer to the artificial flowers due to the flies' positive charge was recorded through the stems. The landing of 20 individuals of intact flies (control) over the flowers induced a mean potential of 9.23 ± 1.21 mV (SD = 6.87, n = 20), while in the case of flies with propleuron hairs that were removed, the landing of 20 individuals over the flowers induced no potential change (Fig 4). The charge was induced exactly before fly landings over the flowers due to the repulsion force over the same positive charge (Stankovic & Zawadzki 1997) [13].

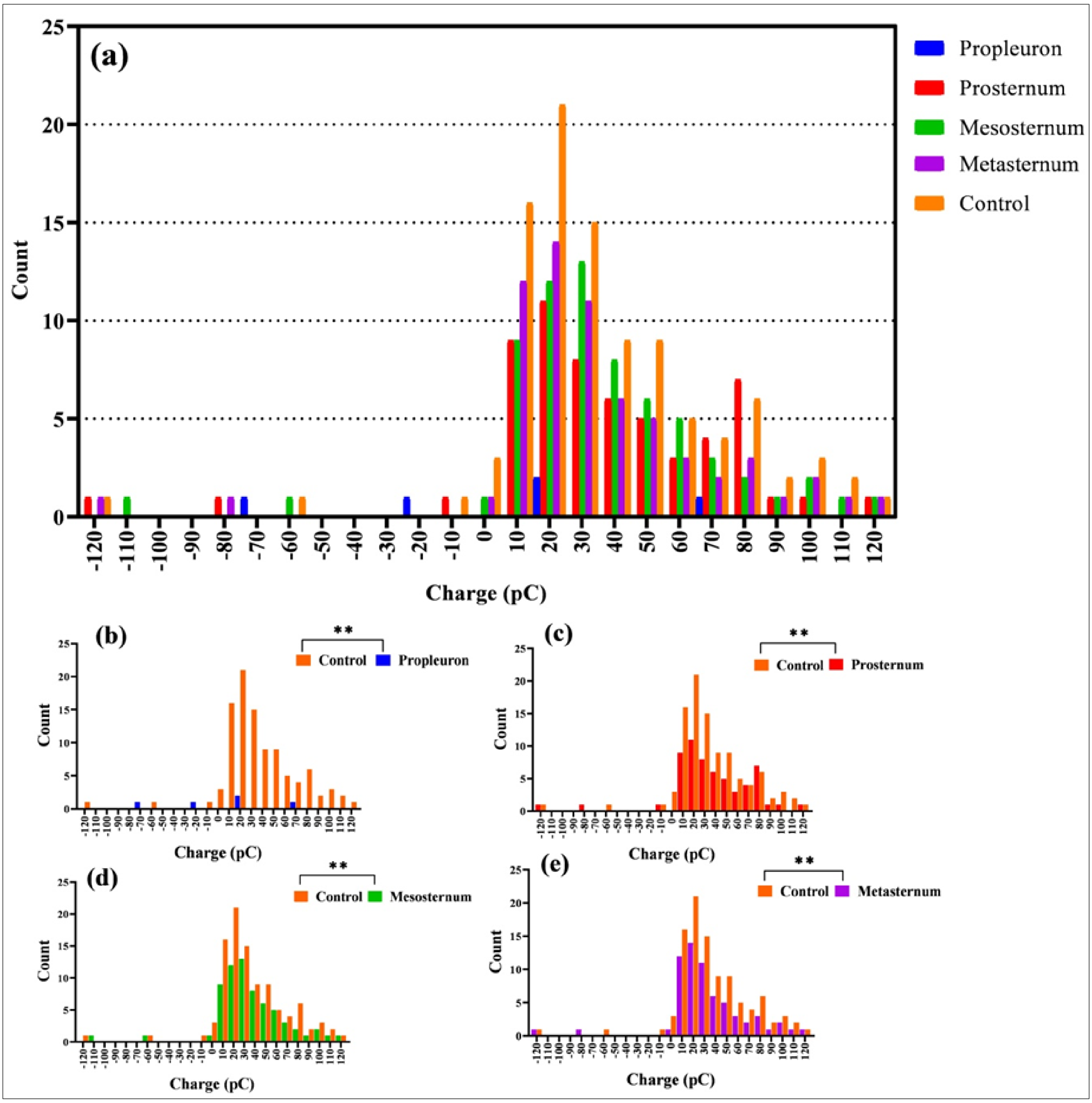

Fig 1: The electrostatic charge induction on hoverflies under different treatments (Propleuron, prosternum, mesosternum, metasternum, and control). The histogram of charge carried by flying hoverflies; measured by the Faraday pail instrument. The opposite net charge of the hoverflies appeared on the Faraday Pail instrument and was measured and analyzed by the attached computer. The intact (control) fly carried a significantly higher positive charge than the other treatments. The lowest positive charge was recorded in case when the propleuron hairs were removed (b, c, d & e).

Table 1: ANOVA table indicates the electrostatic charge induction carried by hoverflies under different treatments (Propleuron, prosternum, mesosternum, metasternum, and control)

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Treatment (between columns)	183.6	4	45.89	F (1.262, 30.29) = 9.790	P=0.0022
Individual (between rows)	1381	24	57.53	F (24, 96) = 12.27	P<0.0001
Residual (random)	450.0	96	4.688		
Total	2014	124			

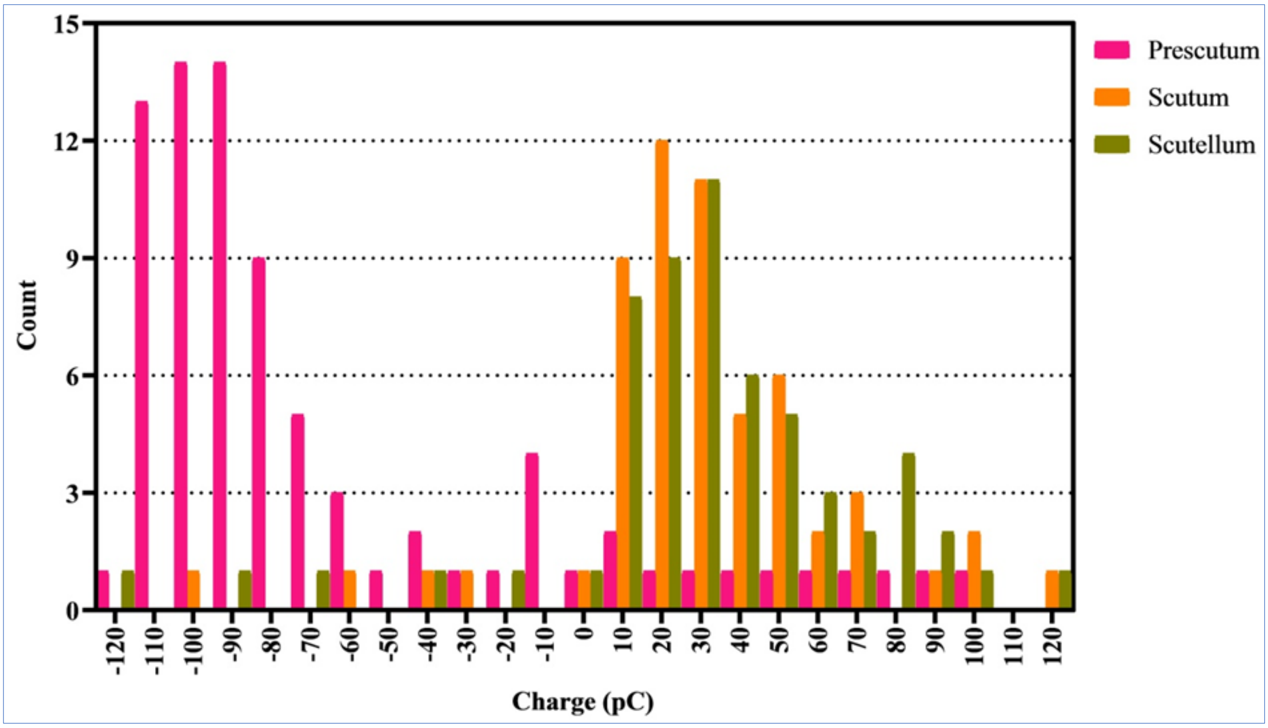

Fig 2: Electrostatic charge induction when the dorsal hairs were removed from the thoracic region (Prescutum, scutum, and scutellum). Fascinating results were obtained when the prescutum hairs have been removed the flies had induces the negative charge.

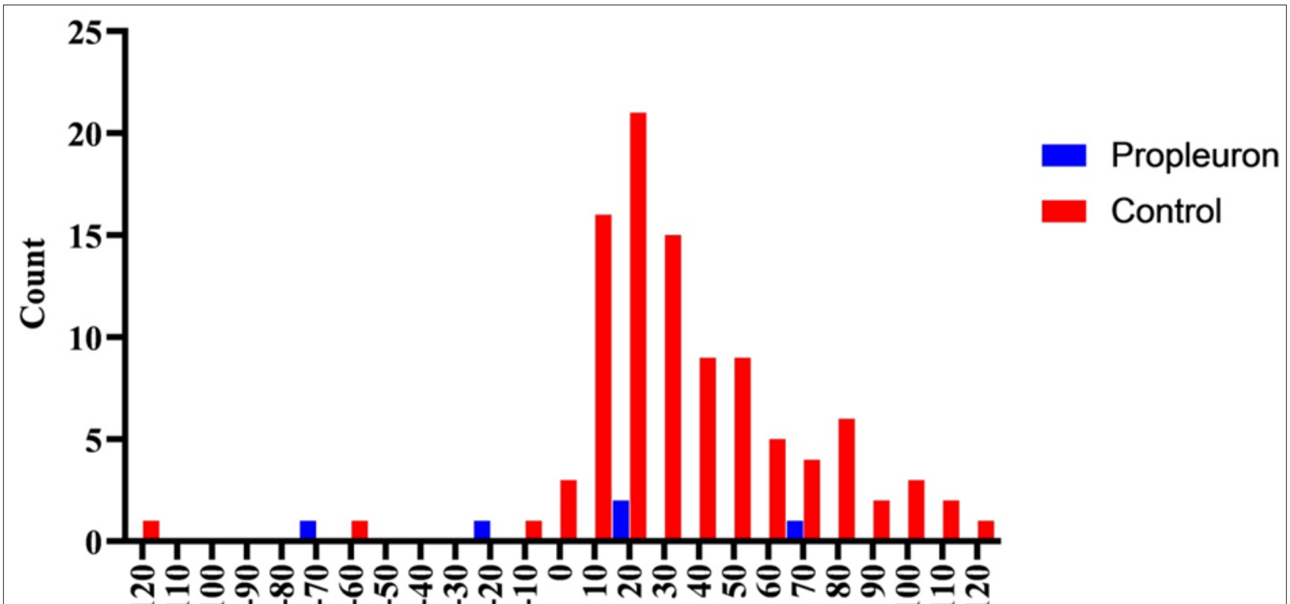

Fig 3: The comparison between the charge induced by ab intact flies (control) and the flies with no propleuron hairs indicates that when the hairs from the propleuron are removed, the flies are unable to induce the charge.

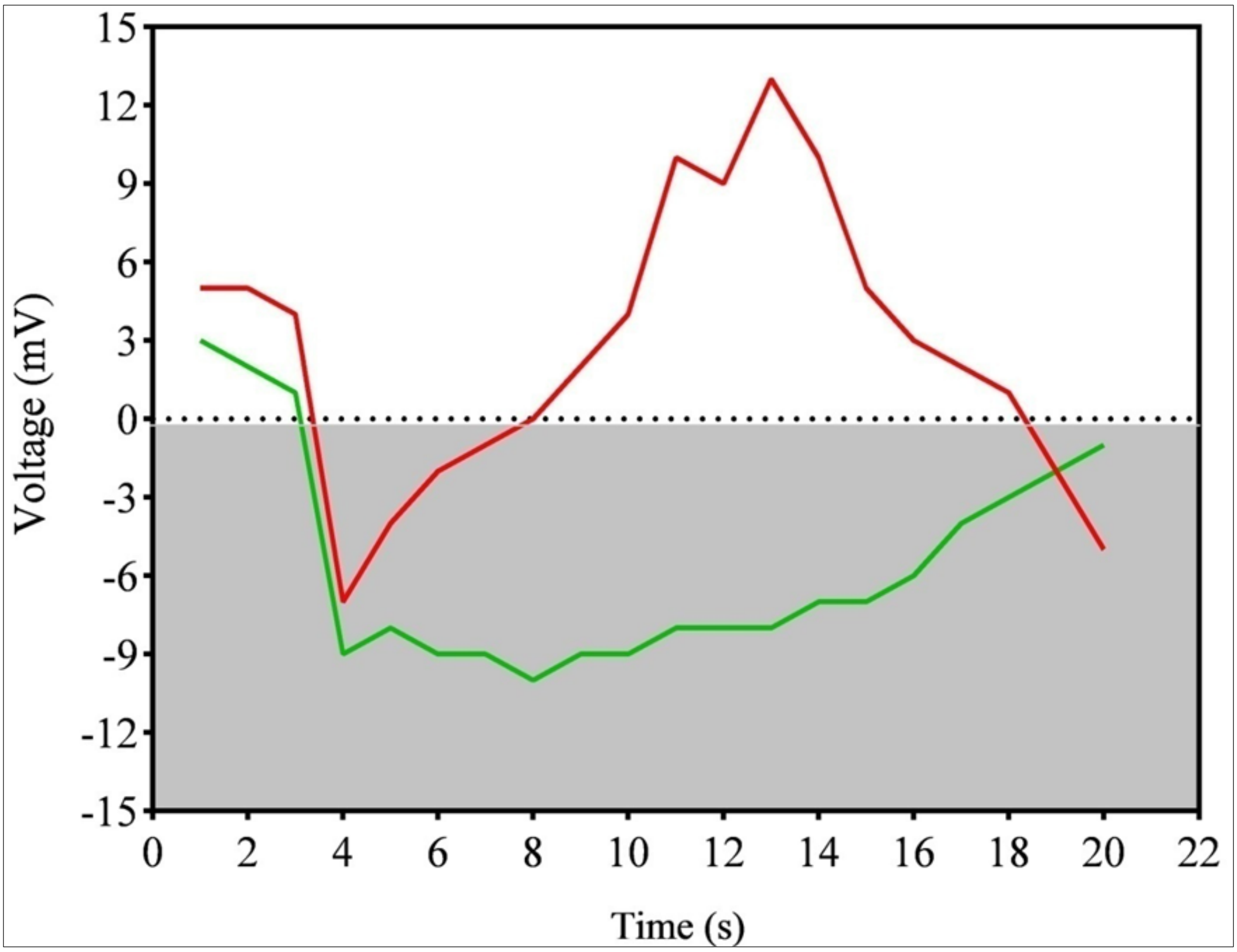

Fig 5: Mean variation in potential with time in the sweet alyssum resulting from flies' landings over the artificially prepared flower. The plot indicates the potential change in charge about time (s) due to intact flies (red) and flies with no propleuron hairs (green).

5. Discussion

Animals from the phylum Arthropoda have been known to produce mechanosensory hairs on their bodies to serve a variety of different purposes (Casas & Dangles, 2010) [2]. The majority of these insects utilize mechanosensory hairs to detect the air currents formed by approaching predators (Tautz & Rostás, 2008; Bathellier *et al*., 2011) [15, 1]. Prior research suggests that honey bees and cockroaches use their antennae to trace electric fields (Newland *et al*., 2008; Casas & Dangles, 2010) [11, 2]. The findings of this study revealed that hoverflies use their thoracic hairs (propleuron hairs) to induce electrostatic charges and electric fields around flowers. Therefore, the study postulates that both non-bee pollinator species' thoracic hairs could act as receptor sites to detect electric fields around the flowers.

The study found that while propleuron hairs play a significant role in electrostatic charge induction, the role of prescutum hair is also important in electrostatic charge induction on hoverflies. Hence, in addition to the vision and olfaction of the pollinators, the detection of electric fields also merits scholarly attention. Thus, the present study posits that propleuron hairs of hoverflies pollinators could serve as the receptor sites in detecting electric fields around the flowers.

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